Minimizing Collective Fuel Use by the Centralized Coordination of Vehicle Platoons

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Computationally Enhanced Mobility

- Developing high-fidelity simulation tools to estimate the energy impact of Connected and Automated Vehicles.
- Developing algorithms for optimally routing vehicles with platooning capabilities.

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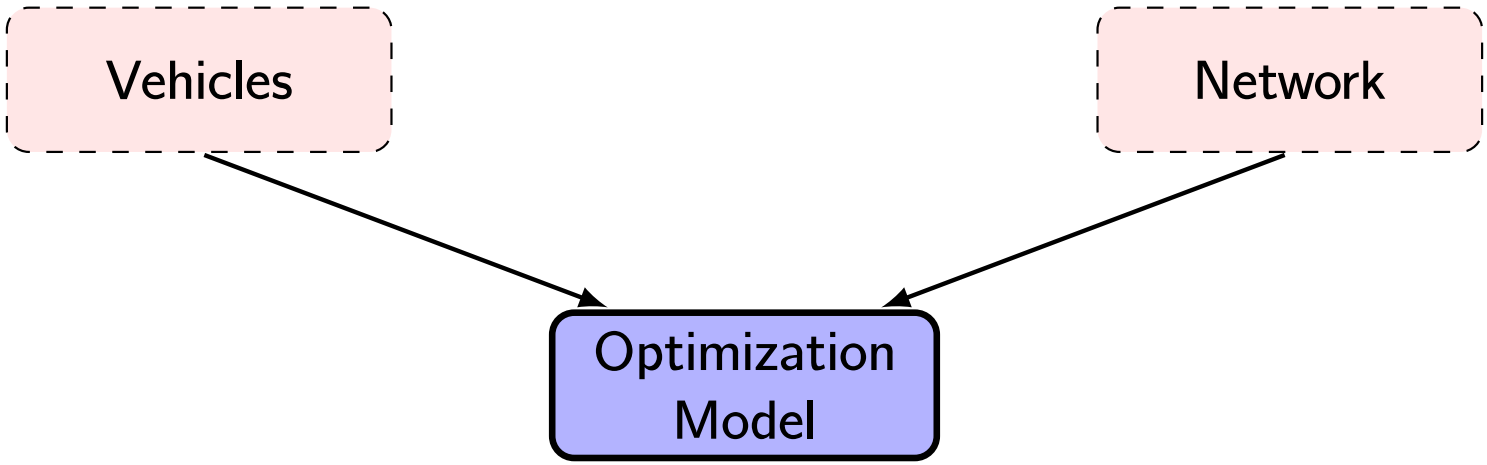
POLARIS

Workflow

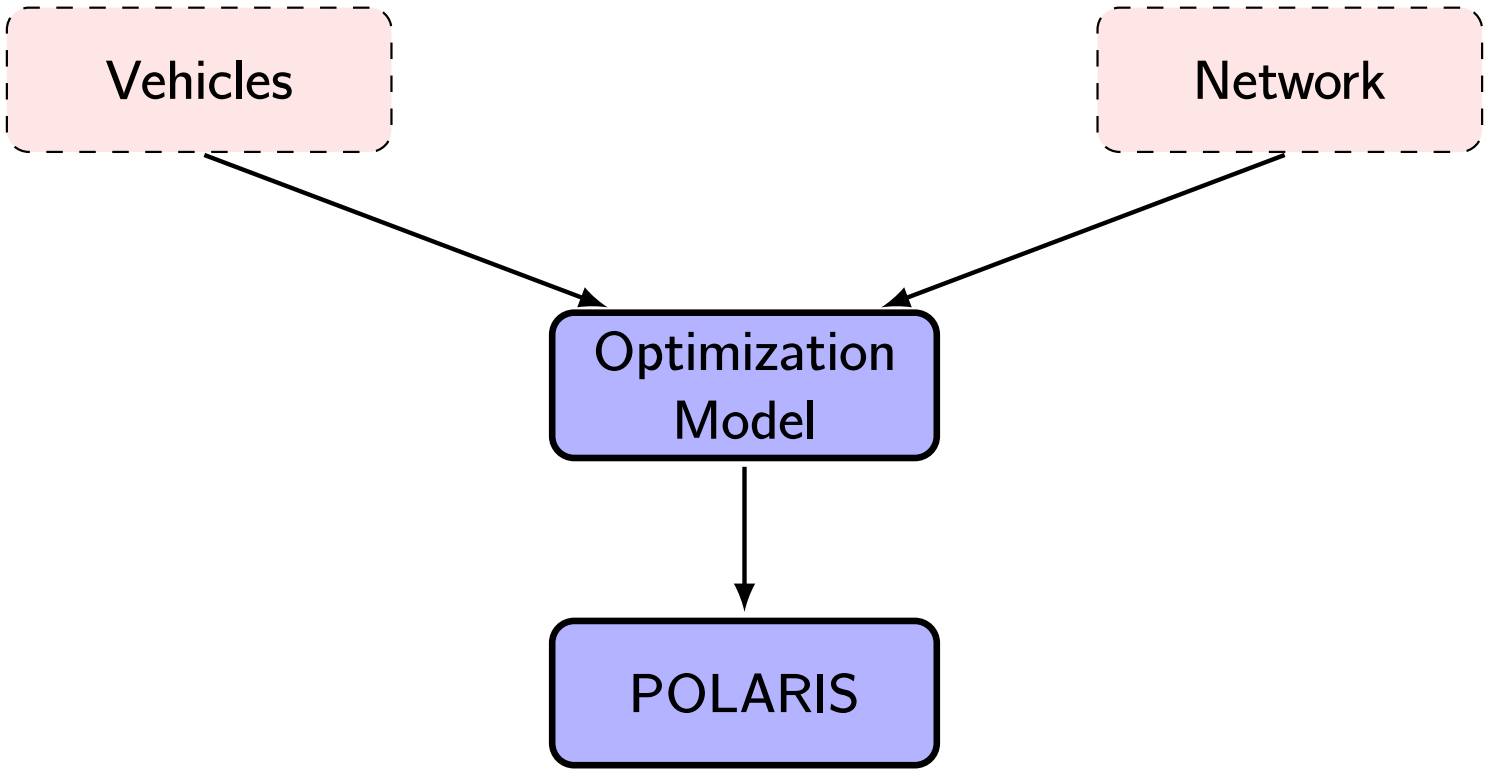
Vehicles

Network

Workflow



Workflow



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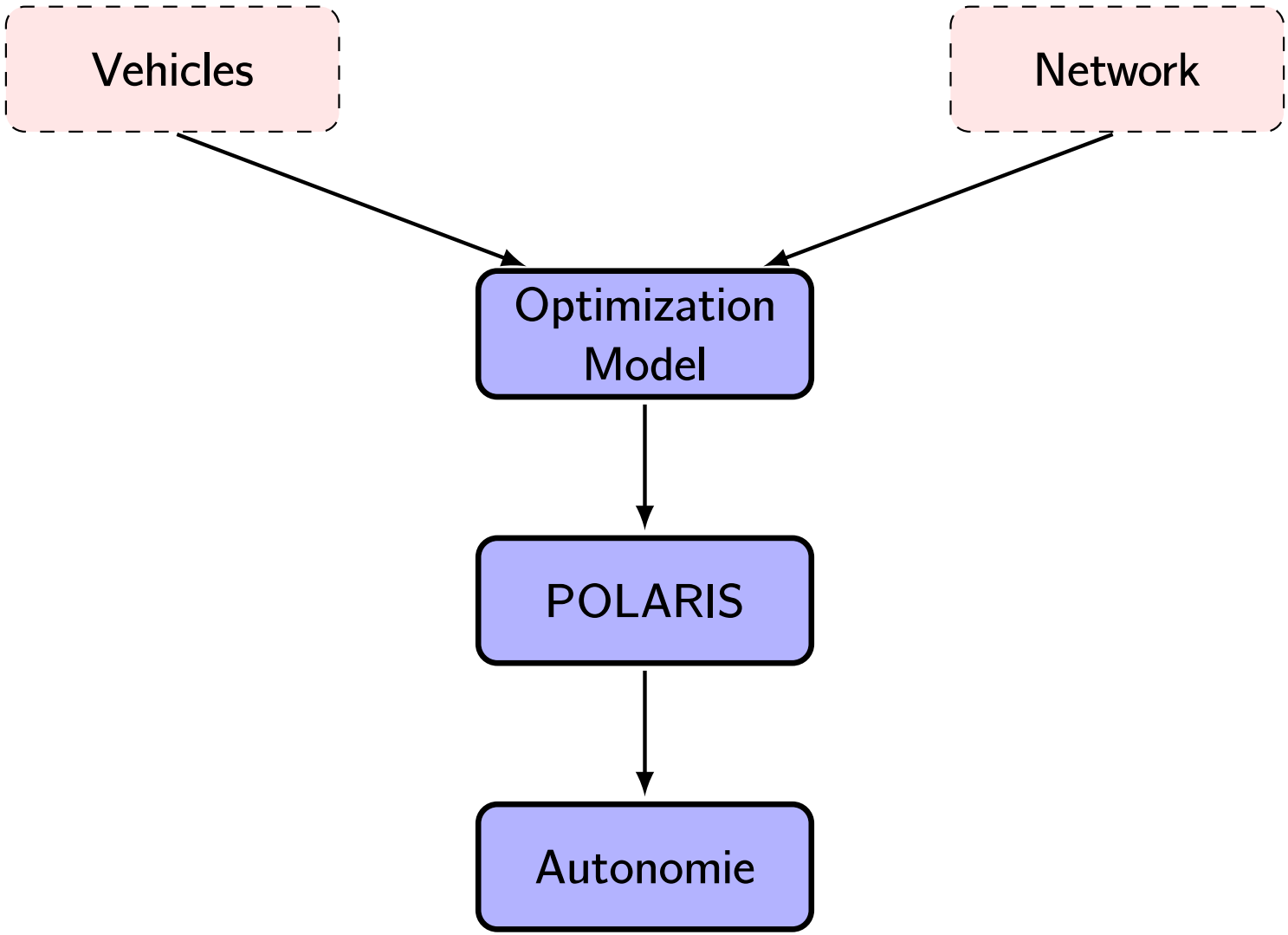
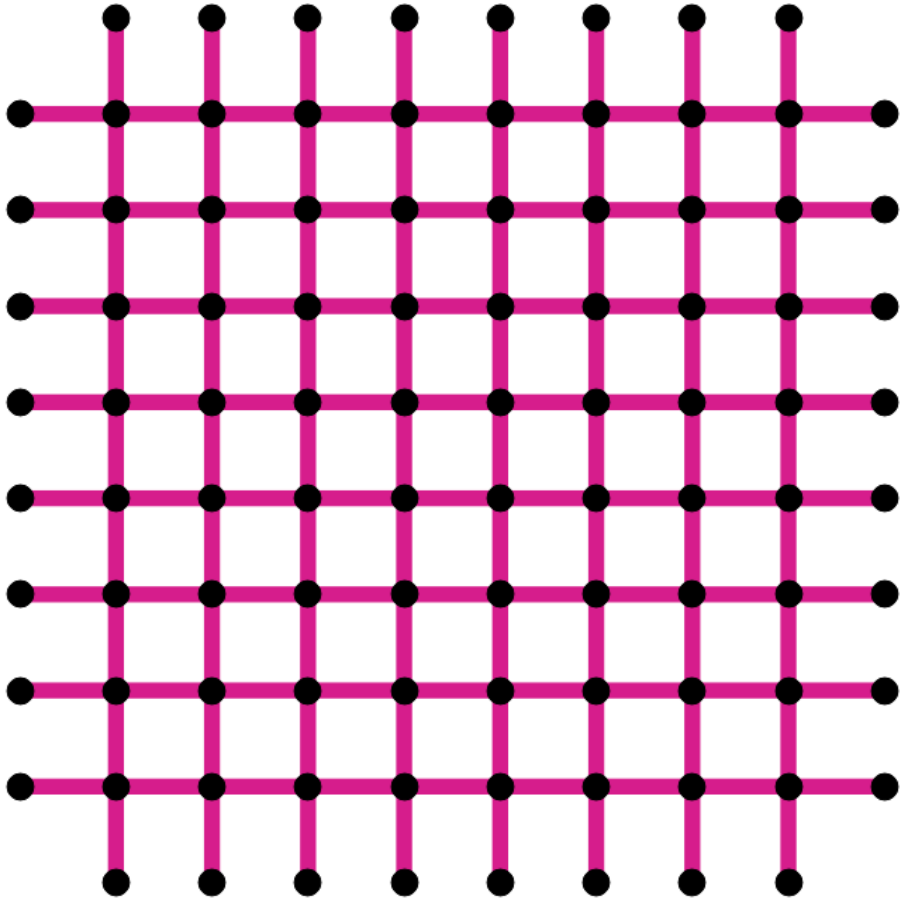


Networks



Animation

- Grid
- Chicago

Optimization Model - Model Parameters

Set	Meaning
V	Vehicles to route
I	Network nodes
$E \subseteq I \times I$	Network edges

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Parameter	Meaning
O_v	$v \in V$ origin node
D_v	$v \in V$ destination node
T_v^O	$v \in V$ origin time
T_v^D	$v \in V$ destination time
C_v^W	waiting cost for $v \in V$
$C_{i,j}$	cost for taking $(i,j) \in E$

Optimization Model - Model Variables

Variable	Meaning
$f_{v,i,j}$	1 if v travels on (i,j)
$q_{v,w,i,j}$	1 if v follows w on (i,j)
$e_{v,i,j}$	Time v enters (i,j)
$w_{v,i}$	Time v waits at i

Optimization Model - Model Constraints

Node outflows must equal inflows.

When platooning, enter times are equal.

Platooning requires at least two vehicles.

Only one vehicle can follow.

T_v^O plus waiting time is the origin enter time.

T_v^D is the final enter time plus the time required to travel the final edge plus waiting at the end.

Intermediate enter times are equal plus the travel and waiting times.

Can't have nonzero enter time if there is no flow.

Can't have nonzero wait time if there is no flow.

Platoon requires flow for the leader.

Platoon requires flow for the followers.

Optimization Model - Example Constraints

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$$e_{v,i,j} \leq M f_{v,i,j}; \quad \forall v \in V,\ (i,j) \in E$$

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Objective:

$$\text{minimize} \quad \sum_{v,i,j} C_{i,j} \left(f_{v,i,j} - \eta \sum_{w} q_{v,w,i,j} \right) + \sum_{v,i} C_v^W w_{v,i}$$

Helping the MIP solver

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Consider v and w platooning on edge (i, j) only if

$$\max\left\{T_v^O + M_{O_v,i},\, T_w^O + M_{O_w,i}\right\} + T_{i,j} \leq \min\left\{T_v^D - M_{D_v,j},\, T_w^D - M_{D_w,j}\right\}$$

where $M_{a,b}$ is the minimum time required to reach b from a.

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If vehicles use a fraction η less fuel when trailing in a platooning and t_s is the shortest time for a vehicle to travel from its origin to destination, it will never travel a path longer than $\frac{1}{1-\eta} t_s$.

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There exists an optimal platoon routing in which no two vehicles split and then merge together.

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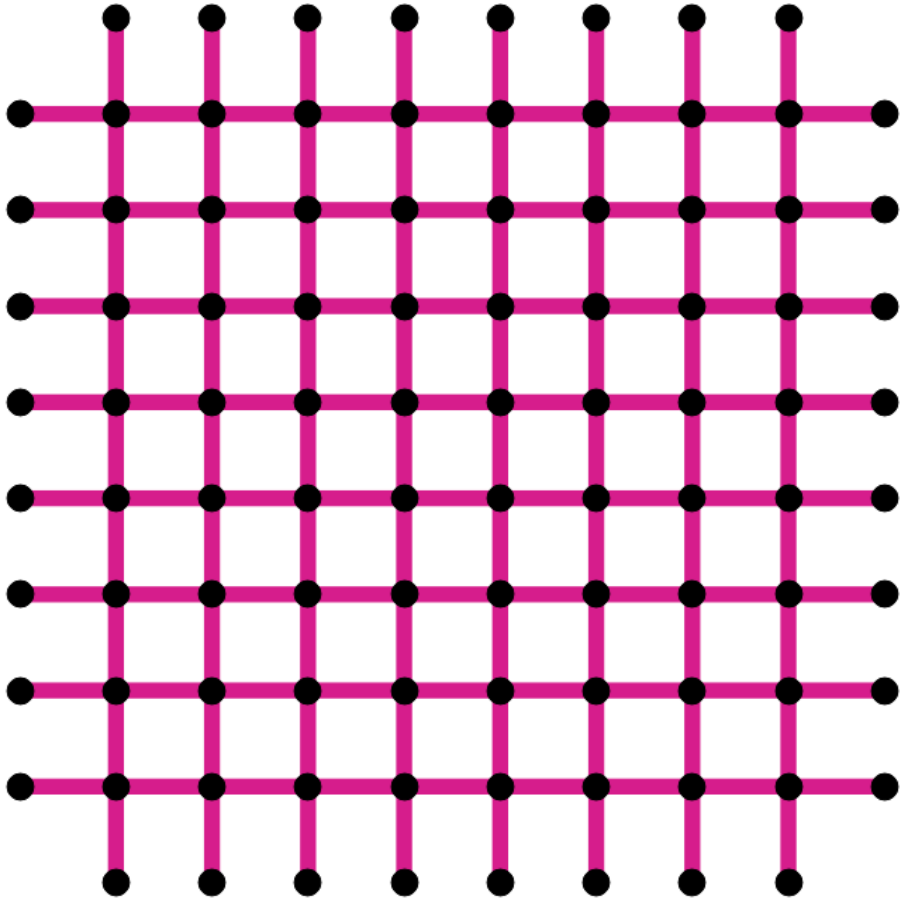
- Running Gurobi until its optimality gap is less than 1e-8

Example solution times



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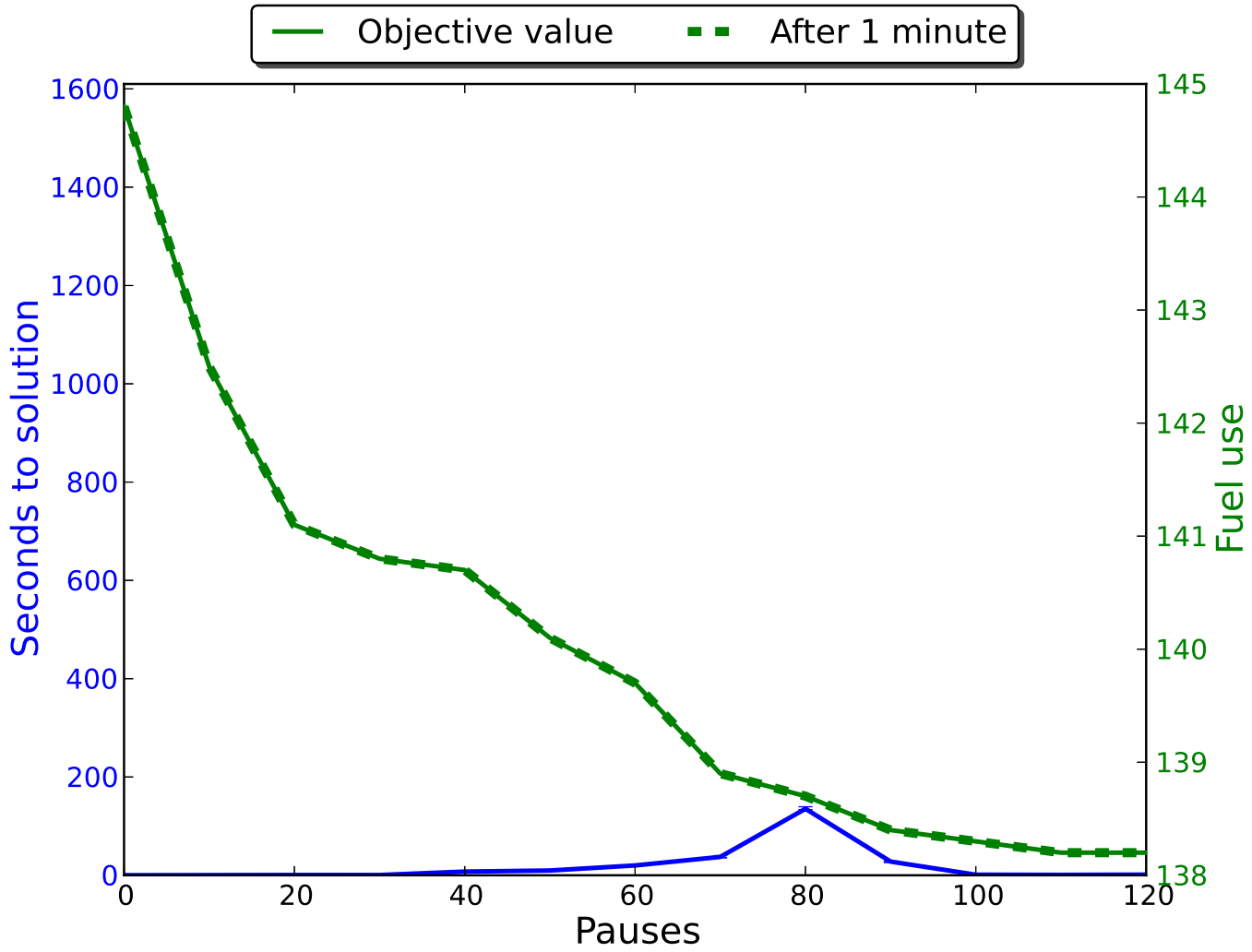

Grid, waiting allowed at intermediate nodes

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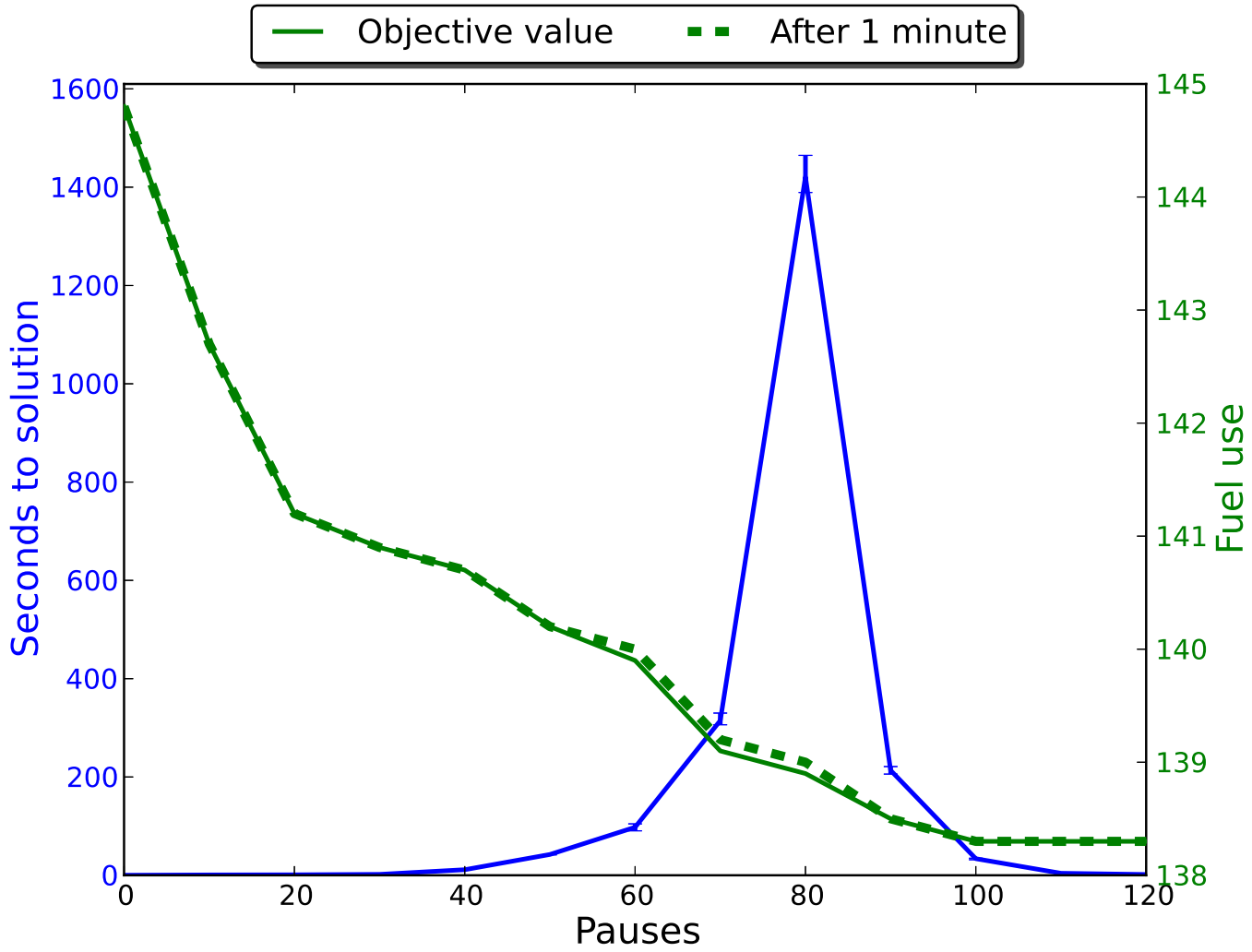

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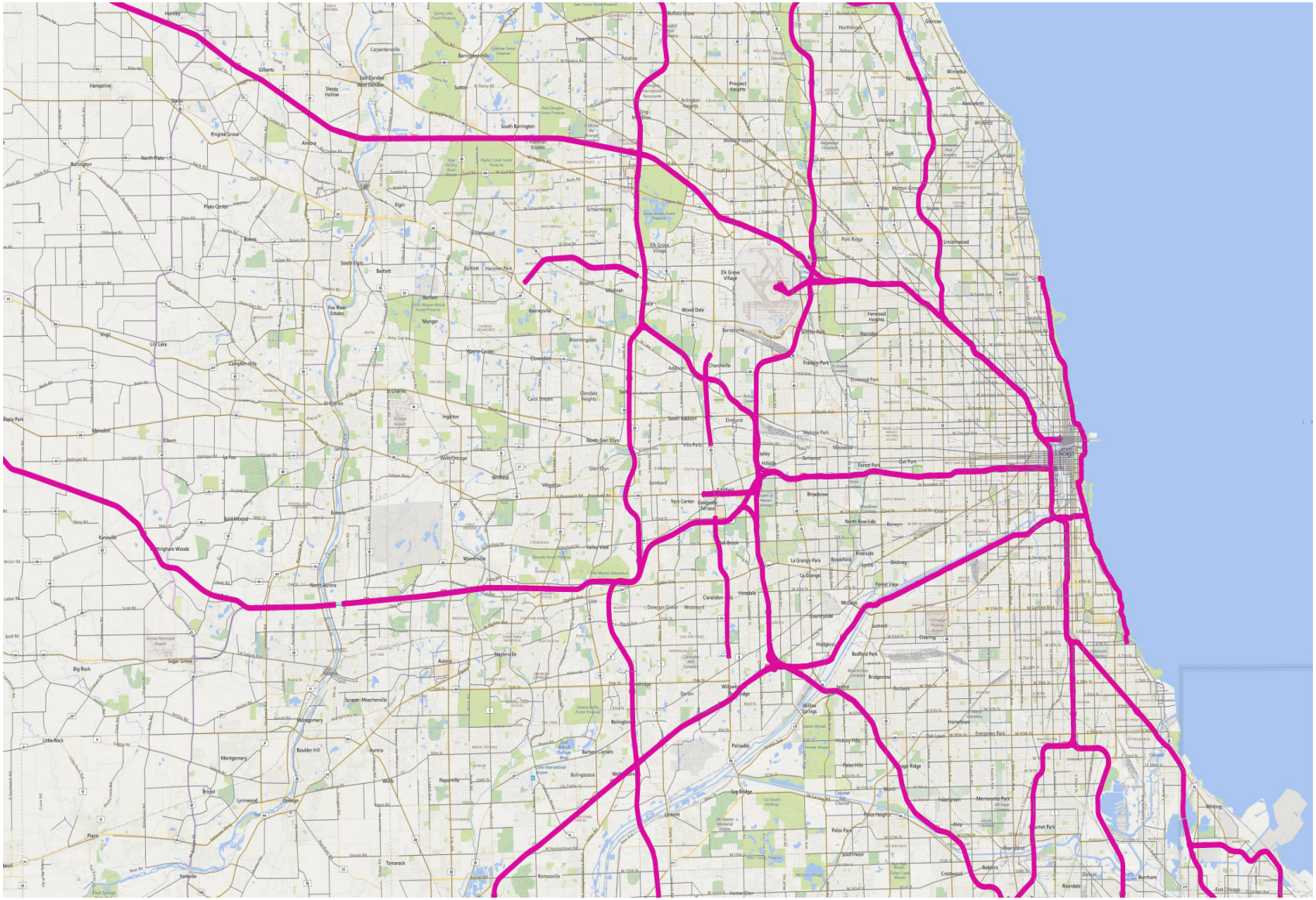

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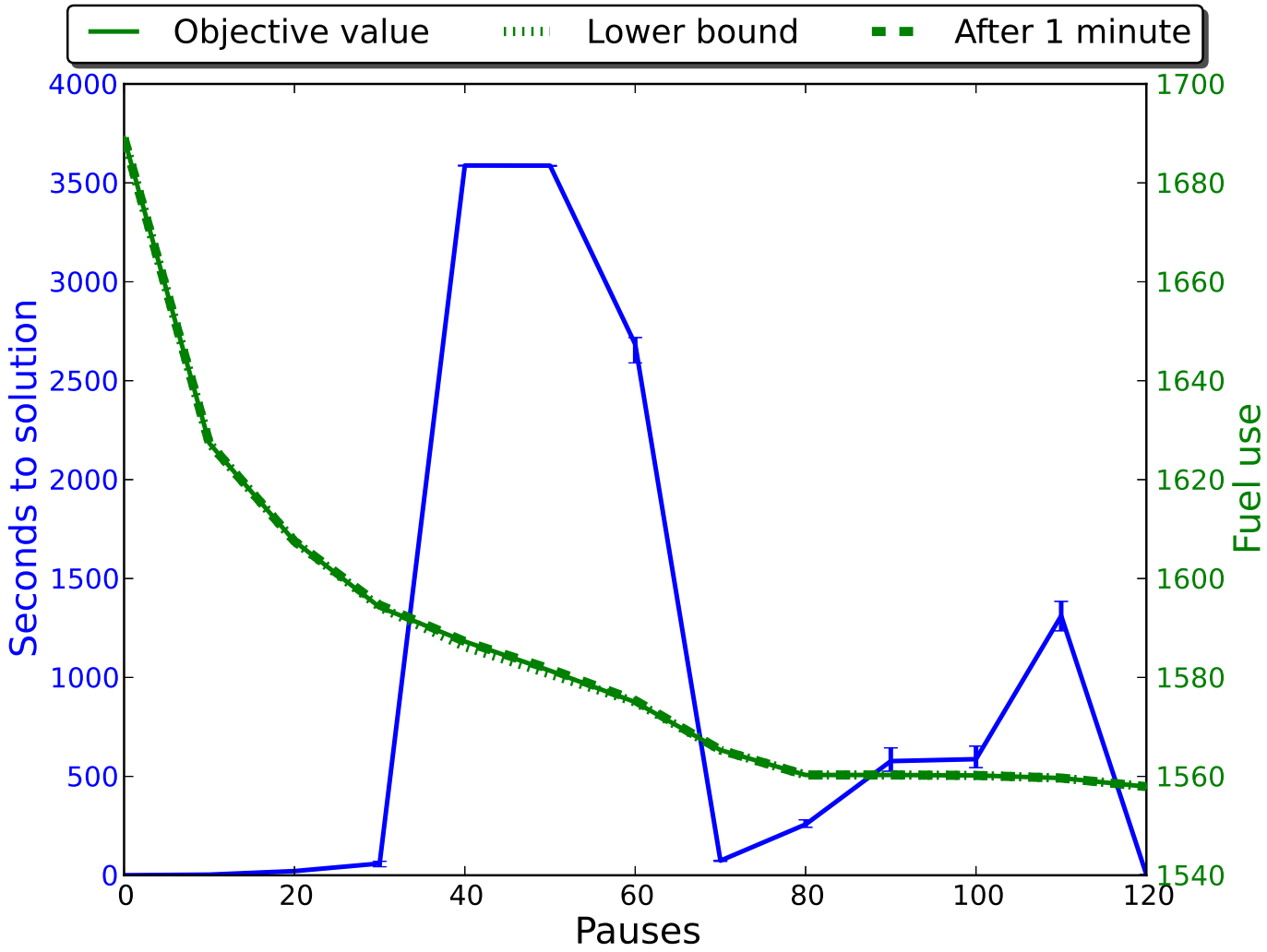

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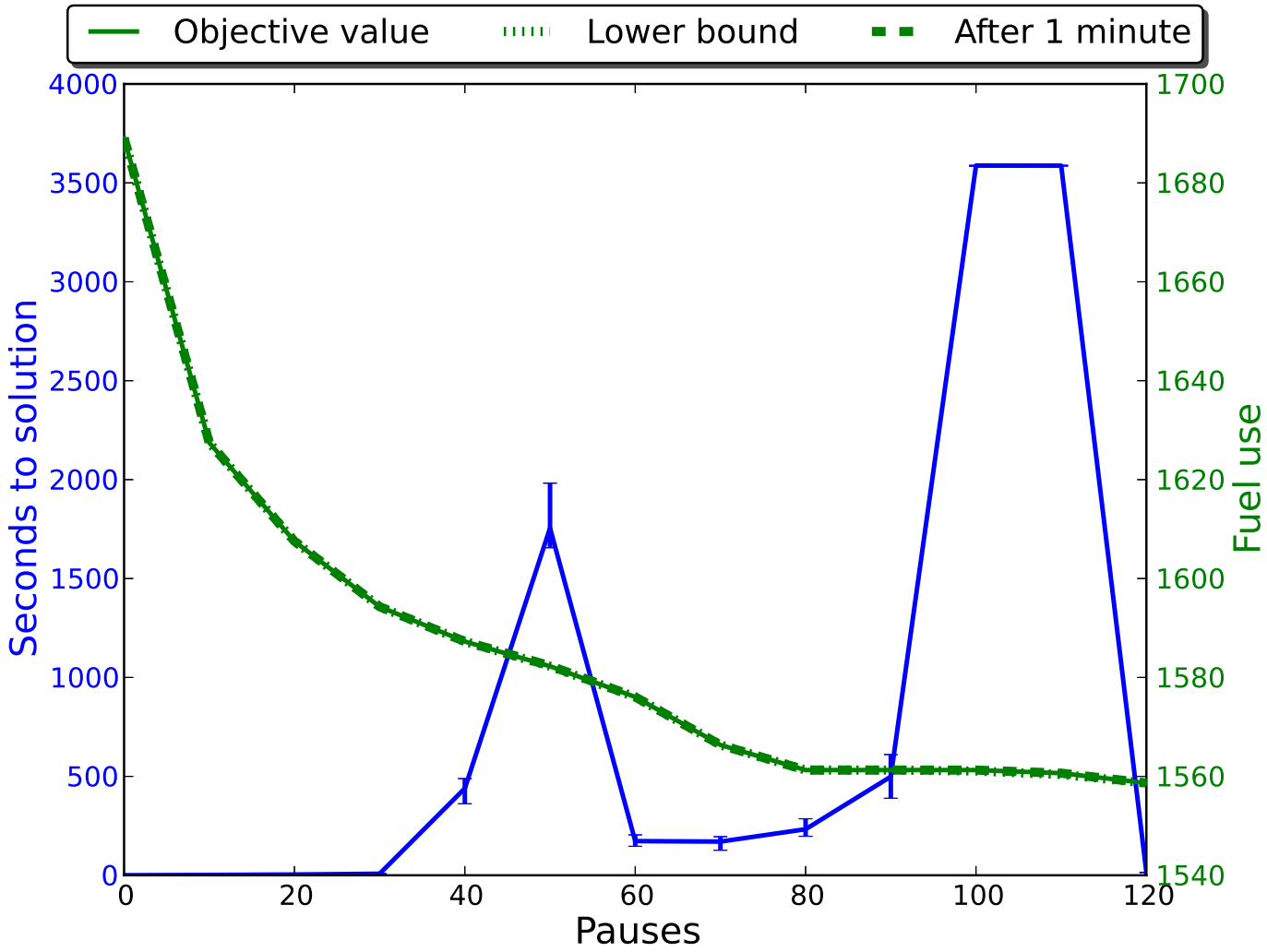

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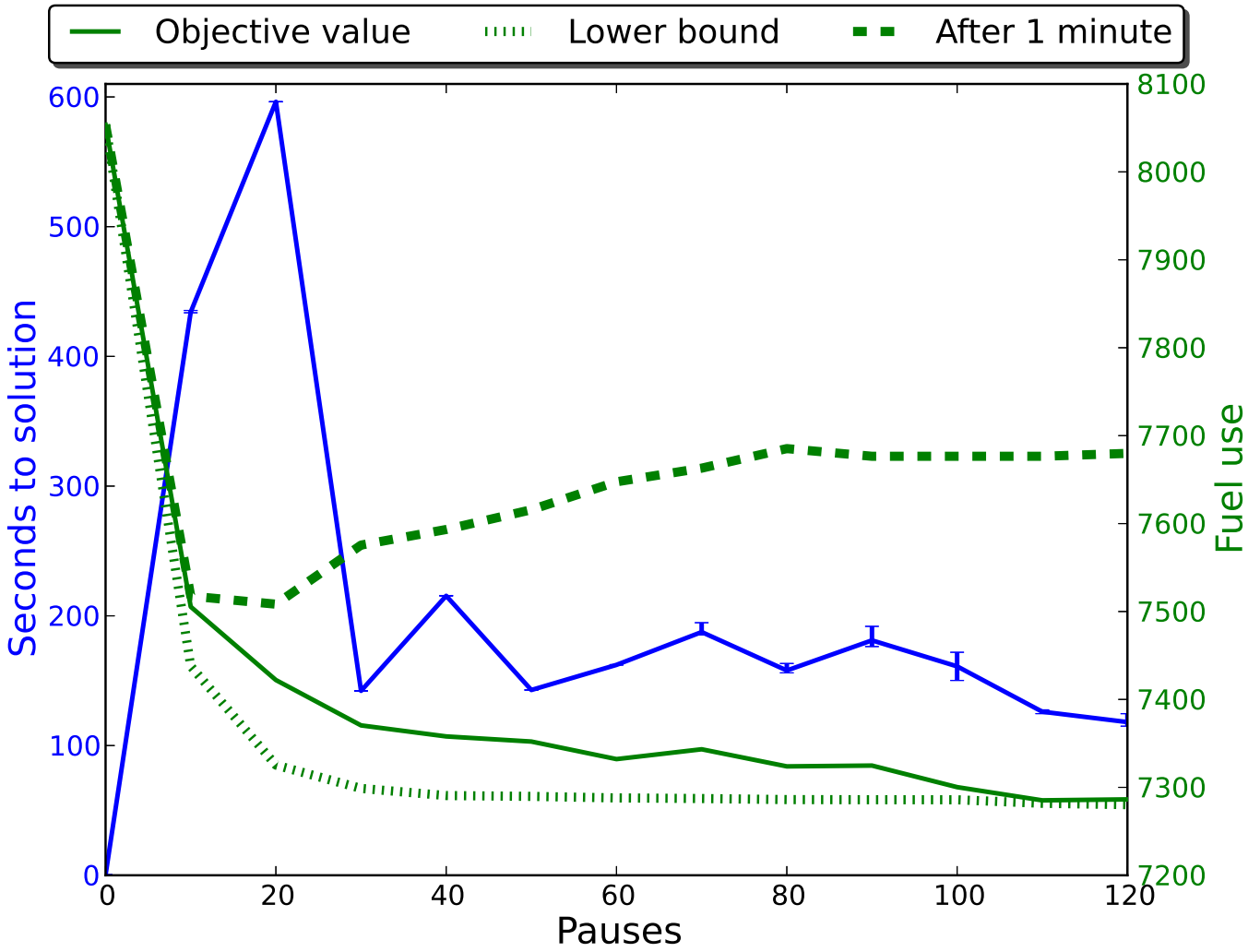

Chicago, 100 vehicles, (20 from each of the 5 most common origin/destination pairs), stopping at 1% optimality gap

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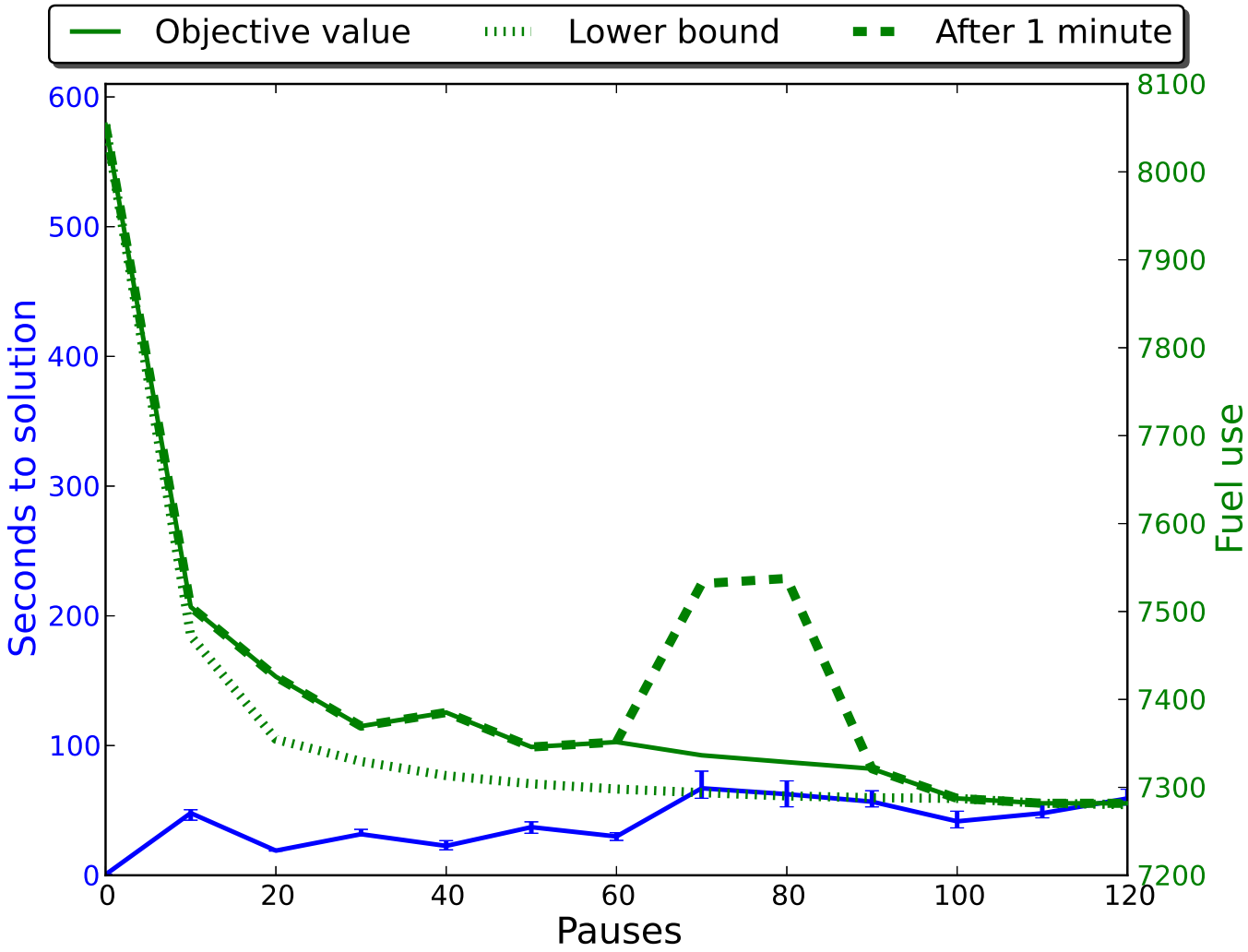


Chicago, 100 vehicles, (20 from each of the 5 most common origin/destination pairs), stopping at 1% optimality gap, using lemmas

Lemma

$$\max\left\{T_v^O, T_w^O\right\} + M_{O_v,D_v} \leq \min\left\{T_v^D, T_w^O\right\}. \tag{1}$$

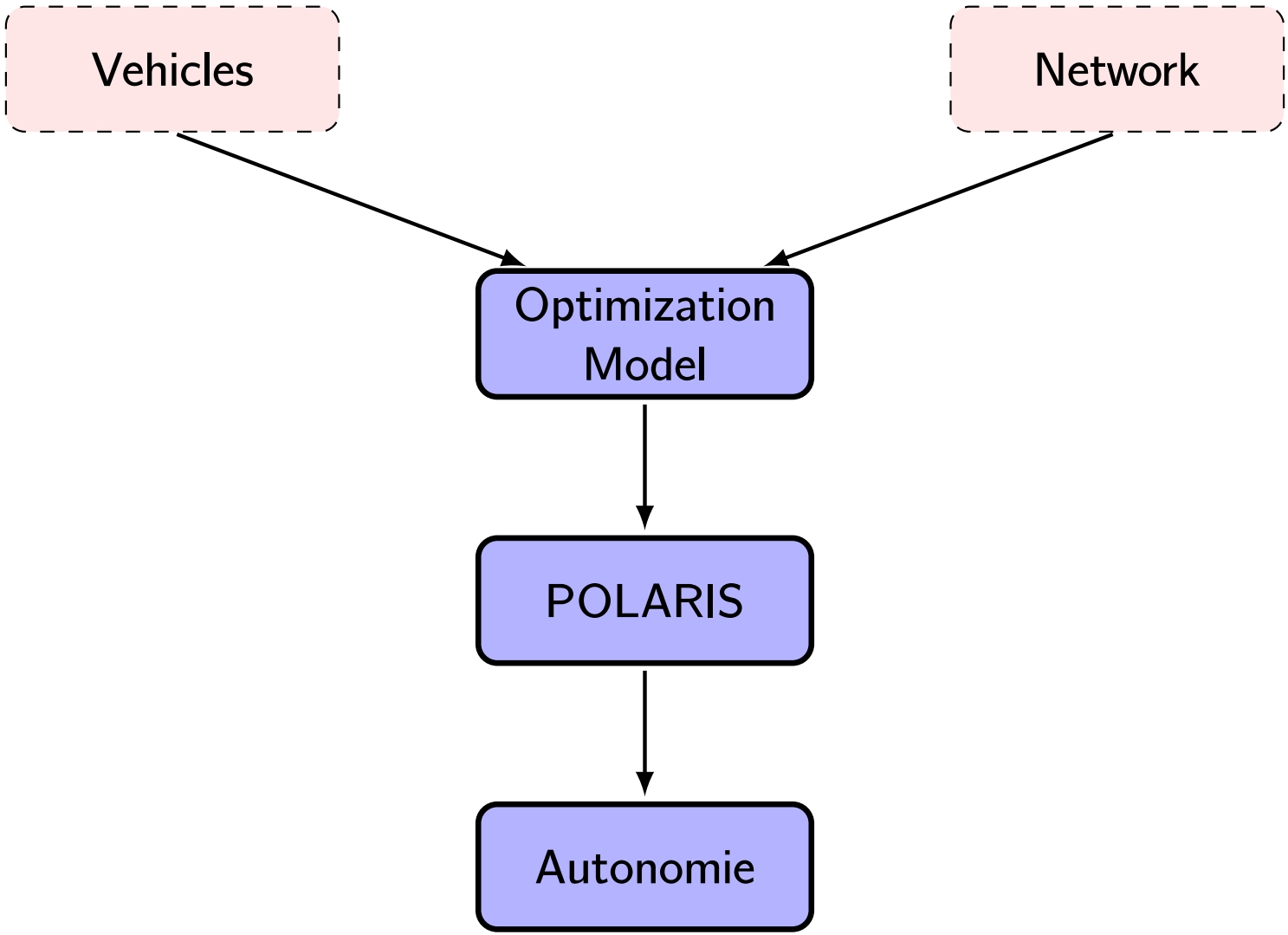
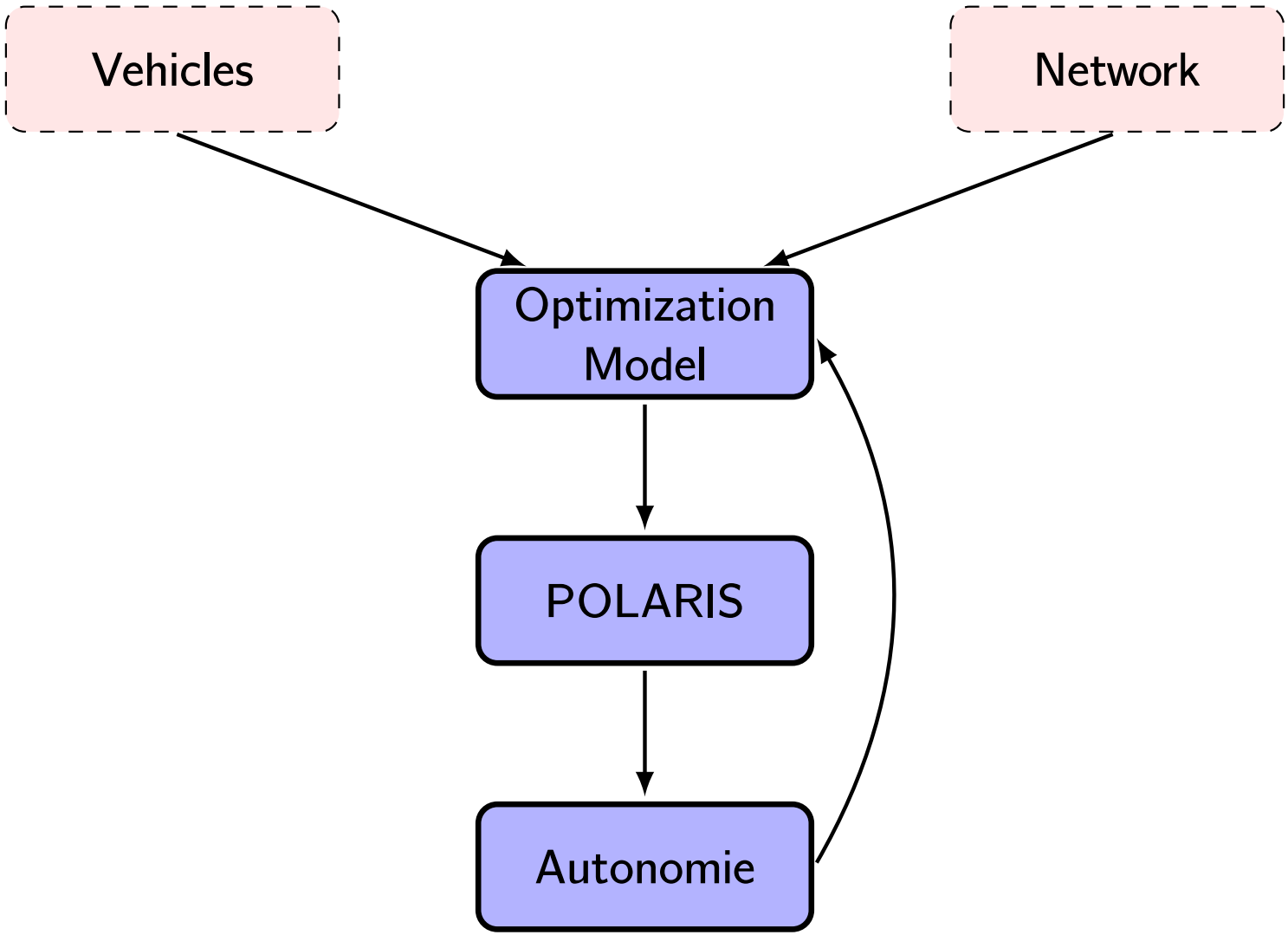
Lemma

Let $v, w \in V$ ***satisfying*** $O_v = O_w$, $D_v = D_w$, ***and*** (1). ***Then if an optimal solution has*** $q_{v,w,i,j} = 0$ ***for any edge*** $(i,j) \in E$, ***there exists an optimal solution with*** $q_{v,w',i,j} = 0$ ***for all*** (i,j) ***all*** w' ***arriving later than*** w.

Current work

- Non-free-flow speeds
- Graph-reduction techniques
- Larger problems
- `http://www.mcs.anl.gov/~jlarson/Platooning/`

Workflow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